

LIGHT EMITTING DIODE ARRAYS WITH IMPROVED LIGHT EXTRACTION

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FIELD OF THE INVENTION

This invention relates to light emitting diode (LED) arrays and, in particular, to
5 LED arrays with integral reflective barriers and methods for making same.

BACKGROUND OF THE INVENTION

Light emitting diodes (LEDs) are being used as light sources in an increasing variety of applications extending from communications and instrumentation to household, automotive and other visual displays. LED arrays comprise a plurality of LEDs arranged 10 on a common substrate. One problem with LED arrays is the significant heat generated by dense concentrations of LEDs. Solutions to the thermal problems associated with LED arrays are the subject of a related application entitled, "*Light Emitting Diodes Packaged For High Temperature Operation*" U.S. Patent Application Serial No. 10/638,579, filed August 11, 2003. The 10/630,579 application is incorporated herein by reference.

15 Another problem in LED arrays concerns illumination efficiency. Illumination efficiency is a measure of the percentage of generated light that actually leaves an LED package and that can serve as useable light in the intended application. Figs. 1 and 2 show a typical LED array 10. LED dies (semiconductor chips) 12 generate light. LED dies 12 are typically box-like in structure with 6 sides. Since they are almost always mounted on 20 one of the light surfaces, the other 5 surfaces are capable of emitting light generated by the

device. Some of the light is absorbed by nearby walls 22 of array package 11, some is reflected back to the emitting die, and some is absorbed directly by nearby LED die 12 in the array. The remainder of the light exits the package.

There is a relationship between illumination efficiency and the thermal problems of

- 5 LED arrays. Self-heating by absorption contributes to thermal problems. Thus, there is a need for an LED packaging arrangement that can increase the illumination efficiency of LED array devices and reduce the thermal problems produced by absorption.

SUMMARY OF THE INVENTION

In accordance with the invention, an illumination device comprises a highly

- 10 thermally conductive substrate having a surface, a plurality of light emitting diodes (LEDs) supported by the surface and arranged in an array to provide illumination. At least one reflective barrier at least partially surrounds each LED. The reflective barrier is shaped to reflect away from the LED light emitted by other LEDs in the array. Advantageously the substrate and reflective barrier are thermally coupled to a heat spreader to dissipate heat.
- 15 The substrate preferably comprises an LTTC-M heat spreader, and the reflective thermal barriers preferably comprise metal ridges or cups.

BRIEF DESCRIPTION OF THE DRAWINGS

The advantages, nature and various additional features of the invention will appear

more fully upon consideration of the illustrative embodiments now to be described in detail

- 20 in connection with the accompanying drawings. In the drawings:

Fig. 1 shows a typical LED array according to the prior art;

Fig. 2 shows a side view of the LED array of Fig. 1;

Fig. 3 shows an exemplary LED package of the prior art;

Fig. 4 shows accordion-tapered reflective thermal barriers;

5 Fig. 5 shows a side view of an LED array with integral tapered thermal barrier reflectors;

Fig. 6 shows a metal cup tapered reflective barrier;

Fig. 7 shows a multi-cup tapered reflective barrier; and

Fig. 8 shows wedge shaped cup tapered barriers arranged to form a circular array.

10 It is to be understood that these drawings are for illustrating the concepts of the invention and are not to scale.

DETAILED DESCRIPTION

This description is divided into two parts. Part I describes the structure and features of light emitting diodes (LEDs) packaged in an array for high illumination efficiency in accordance with the invention and illustrate exemplary embodiments. Part II provides further details of the LTCC-M packaging technology as applicable to LED arrays.
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I. LEDs PACKAGED FOR HIGH ILLUMINATION EFFICIENCY

Fig. 4 illustrates, a tapered barrier reflector 40 fabricated as a periodic array of troughs 41 and tapered reflective ridges 42. This accordion-like structure is a particularly 5 cost effective to manufacture. Metal reflective material can be folded in an accordion-like manner to form the tapered reflective barriers 42. LED dies 12 can be affixed in the troughs 43 between reflective barriers 42.

The barrier reflector 40 can provide a connection to the anode or cathode of LED dies 12. The barrier 40 also serves a thermal cooling function. Heat from the LED die 12 10 can be channeled by the barrier reflector 40 to associated thermal spreaders and to a supporting LTCC-M substrate

Fig. 5 shows an alternative high efficiency LED array 50 comprising discrete reflective barrier structures 52. The reflective thermal barriers 52 are advantageously shaped as fins causing the heat to move from the bottom of the LED 12 through the 15 thermally conductive material (such as solder or silver epoxy 53) to the top of the fin. The length and angle of the fin can be modified by those skilled in the art. The thermal resistance of a LED array package is inversely proportional to the heat dissipating area. Thus the more and longer reflective thermal barriers 52 are, the larger the area for heat dissipation. The LED devices are subsequently encapsulated as by an optically matched 20 clear epoxy 55 formed in a domed shaped in order to increase light extraction and to minimize total internal reflection (TIR).

LED dies 12 are disposed in an array pattern overlying substrate 54. Tapered discrete reflective barriers 52 cause light that would have been absorbed by other die or walls of the package to reflect out of the array package, thus increasing the illumination efficiency. LED dies 12 can be affixed to substrate 54 by solder or epoxy 53.

5 Substrate 54 may be non-conducting or conducting. In the case where substrate 54 is conducting, or has overlaying conductive patterns and traces (not shown), an electrical connection can be made on the mounting surface to either the anode or cathode of LED dies 12. In the case of conductive traces, both the anode and cathode connections can be made on the mounting surfaces of dies 12.

10 Fig. 3 shows further detail of possible electrical connections to die 12. The electrical connections can be made via wire bonds 32 to the LED anode and cathode. Alternatively either the anode or cathode can make electrical contact with a conductor on an insulating substrate, or a conductive substrate. In this case, the remaining terminal can then be connected to dies 12 by a single wire bond. LED die can be soldered (to a metal 15 substrate 36 or overlying conductor 35) or they can be epoxied to substrate 36. A typically translucent or transparent package wall 34 can support a translucent or transparent LED encapsulate 31.

20 Turning back to Fig. 5, it can be seen that liquid epoxy 53 can be deposited on a metal conductor 52 and conductor 52 can be attached to substrate 54. Conductor 52 can be thick film, thin film, electro-deposited, a metal laminate, or other suitable electrical and thermal conductor. If no electrical contact is required conductor 52 can be omitted; however additional heat spreading from the die can be accomplished if conductor 52 is

used. Substrate 54 can be a ceramic, multilayer printed wire board, low temperature cofired ceramic (LTCC), LTCC on metal (LTCC-M), high temperature cofired ceramic (HTCC), or other suitable electrical insulator and thermal conductor. Substrate 54 can be an electrically conducting material if electrical contact to die 12 is desirable, or it can be an

5 electrically insulating layer formed between the substrate and die 12.

Fig. 6 is an exploded view that shows a device 60 where the tapered barrier is a reflective cup 61. LED dies 12 can then be affixed within each cup 61. Each cup 61 is affixed to substrate 54 by solder or epoxy. A small hole 62, with a diameter slightly smaller than the width of the die, can be formed in cup 61. The hole 62 allows some of the

10 liquid epoxy or solder to seep into the cup. Die 12 is then placed into the cup on top of the epoxy or solder. Similarly, LED die 12 can be placed in cup 61 and bonded directly through hole 62 to substrate 54 by epoxy or solder. While hole 62 is not required in assembly 60, the hole facilitates fabrication because the additional step of adding epoxy or solder in the cup for the die can be avoided.

15 Cup 61 can be fabricated from aluminum, stainless steel, tin, nickel, or other reflective material. The cups can be formed by stamping , etching, coining, machining, or other manufacturing method. Assembly of an array of LED die in reflective cup tapered barriers can be accomplished using inexpensive pick-and-place assembly.

Fig. 7 illustrates an advantageous embodiment 70 using an array of cups 71. This

20 multi-cup assembly can be pressed, stamped, or otherwise formed from a sheet of metal

72. Cups 71 need not be round and can be elliptical, square, or rectangular in shape. The metal can gauge from 0.002" to 0.030", and it can comprise brass, copper, phosphorous

bronze, beryllium copper, stainless steel, titanium, Inconel, carbon or alloy steel or precious metal.

Fig. 8 shows a circular array 80 created from wedge-shaped sector cups 81. Each wedge 81 can include an LED die 12, and the sector cups can be arranged in the form of a
5 circle.

Referring to Figs. 9, 10 and 11, yet another method to create a reflecting surface on an LED cavity wall is to metallize the wall of the cavity with a thick or thin reflective metal film 101, such as silver. Then a molten reflecting metal 92 such as solder is applied to use the cavity edge as a capillary holder (Fig. 9). The molten metal will conform to the
10 edge capillary and will shape the reflector cup wall into a parabola shape as seen in assemblies 100 and 110. The middle of the cup can have a metal insert such as a high temperature solder ball 91 (Fig. 10) or a metal/solder column 111 (Fig. 11).

In all of the above mentioned embodiments, the materials used to form the reflective barriers should have low absorption characteristics in the 300 to 800 nm
15 wavelength range. The barrier surfaces can be dispersive or non-dispersive depending on the application.

It is sometimes desirable to direct light that comes out of the LED on to a certain target. Figure 12 shows a conventional assembly 120 composed of multiple subassemblies 121 illuminating from the periphery of a mushroom-like heat sink 122. The
20 target illumination profile of this subassembly is 360 degrees at an inclination angle θ . In order to direct light at this angle, a truncated cone shape heat sink would have to be

machined. Placing the subassemblies on the angled surface of the heat sink is difficult. Standard surface mount (SMT) technology can not be used. Thus fabrication becomes a complex, laborious and expensive process.

In accordance with this aspect of the invention, reflector walls are used as guides
5 for reflecting light directionally from an array. The barrier surfaces can be shaped as light guides to reflect the light at a particular target angle. Figure 13 depicts the outline of a stamped reflector cup 131 adapted for a directional lighting array. Direction at an angle θ is accomplished by shaping the cup. The die will sit at an angle due to the slope of the cup. The LED die will be connected with the substrate using conductive epoxy and wired using
10 a wirebond though hole 132. The die/cup assemblies can be mounted on a planar substrate by SMT assembly.

Another advantageous embodiment is depicted in Fig. 14. The LED 12 can be placed using standard SMT equipment parallel with the thermally conductive substrate. A glob of conductive epoxy 142 is dispensed on the bottom of the cup 141, attaching to the
15 board both the cup and the LED die. The cup 141 is shaped so that the majority of the rays come out at angle θ . The electrical connection can be made with a gold wirebond 32 through a hole 132 in the cup. This embodiment is advantageous due to its simplicity and ease of volume manufacturing. Cup 141 can be fabricated from aluminum, stainless steel, tin, nickel, or other reflective material. It can be formed by stamping , etching, coining,
20 machining, or other manufacturing method.

II. LTCC-M Packaging

LTCC-M packaging is particularly suitable for dispensing heat generated by densely packed arrays of LED die. This section highlights some of the important aspects of LTCC-M packaging applicable to fabricating LED arrays with reflective barriers.

5 Multilayer ceramic circuit boards are made from layers of green ceramic tapes. A green tape is made from particular glass compositions and optional ceramic powders, which are mixed with organic binders and a solvent, cast and cut to form the tape. Wiring patterns can be screen printed onto the tape layers to carry out various functions. Vias are then punched in the tape and are filled with a conductor ink to connect the wiring on one
10 green tape to wiring on another green tape. The tapes are then aligned, laminated, and fired to remove the organic materials, to sinter the metal patterns and to crystallize the glasses. This is generally carried out at temperatures below about 1000°C, and preferably from about 750-950°C. The composition of the glasses determines the coefficient of thermal expansion, the dielectric constant and the compatibility of the multilayer ceramic
15 circuit boards to various electronic components. Exemplary crystallizing glasses with inorganic fillers that sinter in the temperature range 700 to 1000 °C are Magnesium Alumino-Silicate, Calcium Boro-Silicate, Lead Boro-Silicate, and Calcium Alumino-Boricate.

More recently, metal support substrates (metal boards) have been used to support
20 the green tapes. The metal boards lend strength to the glass layers. Moreover since the green tape layers can be mounted on both sides of a metal board and can be adhered to a metal board with suitable bonding glasses, the metal boards permit increased complexity

and density of circuits and devices. In addition, passive and active components, such as resistors, inductors, and capacitors can be incorporated into the circuit boards for additional functionality. Where optical components, such as LEDs are installed, the walls of the ceramic layers can be shaped and / or coated to enhance the reflective optical properties of
5 the package, or reflective barriers as described herein in Part I, can be used to further improve both the illumination and thermal efficiency of the LED array package.

This system, known as low temperature cofired ceramic-metal support boards, or LTCC-M, has proven to be a means for high integration of various devices and circuitry in a single package. The system can be tailored to be compatible with devices including
10 silicon-based devices, indium phosphide-based devices and gallium arsenide-based devices, for example, by proper choice of the metal for the support board and of the glasses in the green tapes.

The ceramic layers of the LTCC-M structure must be matched to the thermal coefficient of expansion of the metal support board. Glass ceramic compositions are
15 known that match the thermal expansion properties of various metal or metal matrix composites. The LTCC-M structure and materials are described in U.S. Patent No. 6,455,930, "*Integrated heat sinking packages using low temperature co-fired ceramic metal circuit board technology*", issued Sep. 24, 2002 to Ponnuswamy, et al and assigned to Lamina Ceramics. U.S. Patent No. 6,455,930 is incorporated by reference herein. The
20 LTCC-M structure is further described in U.S. Patent No. 5,581,876, 5,725,808, 5,953,203, and 6,518502, all of which are assigned to Lamina Ceramics and also incorporated by reference herein.

The metal support boards used for LTCC-M technology do have a high thermal conductivity, but some metal boards have a high thermal coefficient of expansion, and thus a bare die cannot always be directly mounted to such metal support boards. However, some metal support boards are known that can be used for such purposes, such as metal
5 composites of copper and molybdenum (including from 10-25% by weight of copper) or copper and tungsten (including 10-25% by weight of copper), made using powder metallurgical techniques. Copper clad Kovar®, a metal alloy of iron, nickel, cobalt and manganese, a trademark of Carpenter Technology, is a very useful support board. AlSiC is another material that can be used for direct attachment, as can aluminum or copper
10 graphite composites.

Another instance wherein good cooling is required is for thermal management of flip chip packaging. Densely packed microcircuitry, and devices such as decoder / drivers, amplifiers, oscillators and the like which generate large amounts of heat, can also use LTCC-M techniques advantageously. Metallization on the top layers of an integrated
15 circuit bring input/output lines to the edge of the chip so as to be able to wire bond to the package or module that contains the chip. Thus the length of the wirebond wire becomes an issue; too long a wire leads to parasitics. The cost of very high integration chips may be determined by the arrangement of the bond pads, rather than by the area of silicon needed to create the circuitry. Flip chip packaging overcomes at least some of these problems by
20 using solder bumps rather than wirebond pads to make connections. These solder bumps are smaller than wire bond pads and, when the chip is turned upside down, or flipped, solder reflow can be used to attach the chip to the package. Since the solder bumps are small, the chip can contain input / output connections within its interior if multilayer

packaging is used. Thus the number of die in it, rather than the number and size of bond pads will determine the chip size.

However, increased density and integration of functions on a single chip leads to higher temperatures on the chip, which may prevent full utilization of optimal circuit 5 density. The only heat sinks are the small solder bumps that connect the chip to the package. If this is insufficient, small active or passive heat sinks must be added on top of the flip chip. Such additional heat sinks increase assembly costs, increase the number of parts required, and increase the package costs. Particularly if the heat sinks have a small thermal mass, they have limited effectiveness as well.

10 In the simplest form of the present invention, LTCC-M technology is used to provide an integrated package for a semiconductor component and accompanying circuitry, wherein the conductive metal support board provides a heat sink for the component. A bare semiconductor die, for example, can be mounted directly onto a metal base of the LTCC-M system having high thermal conductivity to cool the semiconductor 15 component. In such case, the electrical signals to operate the component must be connected to the component from the ceramic.

Indirect attachment to the metal support board can also be used. In this package, all 20 of the required components are thermally coupled to a metal support board, that can also incorporate embedded passive components such as conductors and resistors into the multilayer ceramic portion, to connect the various components, i.e., semiconductor components, circuits, heat sink and the like, in an integrated package. In the case of LED arrays, where electrical circuit considerations would dictate an insulating material be used,

thermal conduction can be problematic. Here the inventive reflective barriers further serve as thermal spreading devices to help transfer heat received by conduction and radiation through the insulating layer to the metal base.

For a more complex structure having improved heat sinking, the integrated package
5 of the invention combines a first and a second LTCC-M substrate. The first substrate can have mounted thereon a semiconductor device, and a multilayer ceramic circuit board with embedded circuitry for operating the component; the second substrate has a heat sink or conductive heat spreader mounted thereon. Thermoelectric (TEC) plates (Peltier devices) and temperature control circuitry are mounted between the first and second substrates to
10 provide improved temperature control of semiconductor devices. A hermetic enclosure can be adhered to the metal support board.

The use of LTCC-M technology can also utilize the advantages of flip chip packaging together with integrated heat sinking. The packages of the invention can be made smaller, cheaper and more efficient than existing present-day packaging. The metal
15 substrate serves as a heat spreader or heat sink. The flip chip can be mounted directly on the metal substrate, which is an integral part of the package, eliminating the need for additional heat sinking. A flexible circuit can be mounted over the bumps on the flip chip. The use of multilayer ceramic layers can also accomplish a fan-out and routing of traces to the periphery of the package, further improving heat sinking. High power integrated
20 circuits and devices that have high thermal management needs can be used with this new LTCC-M technology.

It is understood that the above-described embodiments are illustrative of only a few of the many possible specific embodiments, which can represent applications of the invention. Numerous and varied other arrangements can be made by those skilled in the art without departing from the spirit and scope of the invention.